NAVIGATION OF THE TSS - 1 MISSION

by

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The Tethered Satellite System Mission was analyzed to determine its impacts on the Mission Control Center (MCC) Navigation section's ability to maintain an accurate state vector for the Space Shuttle during nominal and off-nominal flight operations. Tether dynamics expected on the Shuttle introduces new phenomena when determining the best estimation of its position and velocity. In the following analysis, emphasis was placed on determining the navigation state vectors accuracies resulting when the tether induced forces were and were not modeled as an additional acceleration upon processing tracking measurements around a TSS-1 trajectory. Results of the analyses show that when the forces are not modeled in the state vector generation process, the resulting solution state reflects a solution about the center gravity (c.g.) of the tethered system and not that of the orbiter. The Navigation team's ability to provide accurate state vector estimates necessary for trajectory planning are significantly impeded. In addition to this consequent is an impact to Onboard Navigation state vector accuracies. These analyses will show that in order to preserve an accurate state onboard the orbiter a new operational procedure would have to be adopted. Previous Shuttle missions have shown that an accurate state could be maintained onboard when periodic updates are made utilizing the most accurate solution state vector computed by ground tracking data processing. However, the forces acting on the orbiter are much larger than those which have been modeled during previous mission and must be included in the Onboard Navigation state vector update process. The following analyses will show that significant improvements to state vector accuracies on both the ground and onboard can be achieved when the forces are modeled throughout the TSS-1 mission profile.

Introduction

The introduction of a Tethered Satellite System is new to the MCC Navigation section. The dynamics imposed on the orbiter are much larger than any which have been experienced during previously flown Space Transportation System (STS) missions. Consequently, many pre-mission analyses have been performed to better understand the behavior of a tethered system on the navigation process thereby assuring crew safety and mission success.

The TSS-1 mission is currently schedule for launch in February 1992. Its design includes a 500 kg satellite which will be deployed upward and away from the earth with the aid of a tether to a maximum length of 20 km. The tether will be electrically conductive. The satellite, on the other hand, will be electrically positive and is designed to collect electrons from the ionosphere. The electrons will be passed through the tether to the orbiter and emitted with an electron emitter.

The following sections provide the results of several analyses performed in order to satisfy the above mentioned objectives.

MCC Ground Navigation Overview

The MCC Ground Navigation section is responsible for maintaining accurate knowledge of the Shuttle's position and velocity. This task is accomplished by utilizing the tracking measurements which are provided by space and ground based tracking facilities strategically located throughout the world to compute the orbiter's state.

The analyses discussed in the following sections utilized tracking measurements which were computed around the TSS-1 trajectories using the Spacecraft Tracking Data Simulation (STDS) program. The measurements computed included those from selected C-band stations and both Tracking Data Relay Satellites (TDRSE, TDRSW). C-band stations with a maximum elevation below 3 degrees were not included in the analyses due to their likelihood of inherently introducing erroneous measurements caused by atmospheric refraction.

The Ground Navigation team processes these measurements using trajectory applications inherent in the Mission Operations computer (MOC). Tracking measurements may be processed in both a homogeneous or heterogeneous fashion. The homogeneous method is referred to as the Batch-to-Batch (BB) mode. Measurements from a single tracker are processed to determine the orbiter's state. The heterogeneous technique on the other hand, acknowledges measurements from several trackers for which the orbiter was visible over some orbital timeframe and is referred to as the Superbatch (SB) mode.

The two techniques utilize a weighted least squares processor which computes the state of the orbiter upon satisfying a set of convergence criteria for the measurements, (e.g., Doppler, range, elevation, azimuth), considered in the computation of the state. The quality of the state vector can be determined by minimization the measurement residuals resulting upon execution of the weighted least squares process.

Analysis Overview

The analyses were performed for trajectories defined by the TSS-1 Design Reference Mission (DRM), baselined March 18, 1990. The trajectories included all of the effects of tether dynamics on the orbiter as computed by the Shuttle Tethered Object Control Simulation (STOCS). The tether community at the Johnson Spacecraft Center (JSC) have relied heavily on STOCS to determine the behavior of tethers during Shuttle operations. Current flow expected during the mission were briefly analyzed but did not provide a significant orbital perturbation. Table (1) provides a detailed mission timeline for the DRM.

The analyses were performed to assess whether the MCC Ground Navigation section could successfully support TSS-1 under both nominal and off-nominal flight conditions. The off-nominal scenario which will be discussed is that of the impacts of a tether cut on Shuttle navigation. Also included is an assessment of the frequency at which the Onboard navigation state vector would needed to be updated to preserve flight rules which protect for a safe deorbit in the event of a loss of communication between the ground and crew is experienced.

The primary objective of the Navigation team during STS mission is to provide accurate state vectors to the Flight Dynamics Officer (FDO) to assist in trajectory planning (e.g., translational maneuvers, deorbit burns, contingency operations, etc.). The configuration of the tethered system introduces larger external forces on the orbiter than have been experienced in previous missions. There also exist the phenomenon which in given two orbiting bodies of different masses, attached by a tether, a center of gravity (c.g.) point is defined along the tether. Experience has shown that when processing tracking measurements around a trajectory influenced by tethered dynamics, resulting solution state vectors may be biased to reflect solutions about the c.g. of the system and not that of the orbiter. The following analyses will show that successful navigation of the TSS-1 mission can only be achieved by modeling the tether forces as an additional acceleration when computing the orbiter's state.

Table 1
ATTITUDE TIMELINE

ATTITUDE	TIME (DY:HR:MIN:SEC)	MODE	P/Y/R (DEG)			TETHER LENGTH (KM)	PHASE
1	1:00:00:00	LVLH	30.0	180.0	0.0	0.00	
2	1:00:45:00	LVLH	40.0	180.0	0.0	0.00	
3	1:01:46:00	LVLH	30.0	180.0	0.0	2.40	
4	1:01:57:00	LVLH	15.0	180.0	0.0	3.00	DEPLOY
5	1:02:07:30	LVLH	5.5	180.0	0.0	4.50	
6	1:02:38:30	LVLH-	-22.0	180.0	0.0	5.80	
7	1:04:55:30	LVLH	-25.5	180.0	0.0	11.30	
8	1:07:16:00	LVLH	43.7	-51.4	37.6	20.00	
9	1:07:46:00	LVLH	43.7	51.4	-37.6	20.00	
10	1:08:21:00	LVLH	-25.5	180.0	0.0	20.00	
11	1:10:16:00	LVLH	43.7	-51.4	37.6	20.00	ON-STATION 1
12	1:10:46:00	LVLH	43.7	51.4	-37.6	20.00	
13	1:11:24:30	LVLH	-25.5	180.0	0.0	20.00	
14	1:13:16:00	LVLH	43.7	-51.4	37.6	20.00	
15	1:13:46:00	LVLH	43.7	51.4	-37.6	20.00	
16	1:14:20:00	LVLH	-25.5	180.0	0.0	20.00	
17	1:14:46:00	LVLH	43.7	-51.4	37.6	20.00	
18	1:15:06:00	LVLH	25.5	0.0	0.0	20.00	
19	1:19:26:00	LVLH	23.0	0.0	0.0	11.50	
20	1:21:27:00	LVLH	25.0	0.0	0.0	3.40	
21	1:21:46:00	LVLH	29.0	0.0	0.0	2.80	RETRIEVAL 1
22	1:21:50:00	LVLH	33.0	0.0	0.0	2.70	
23	1:22:04:00	LVLH	37.5	0.0	0.0	2.50	
24	1:23:13:00	LVLH	123.1	43.4	-133.5	2.40	
25	1:23:13:00	LVLH	-37.5	180.0	0.0	2.40	
26	1:23:33:00	LVLH	123.1	-43.4	0.0	2.40	ON-STATION 2
27	2:01:28:00	LVLH	37.5	0.0	0.0	2.40	
28	2:01:43:00	LVLH	0.0	0.0	0.0	2.40	
29	2:02:03:00	LVLH	-10.0	0.0	0.0	2.10	
30	2:03:51:00	LVLH	-20.0	0.0	0.0	1.81	RETRIEVAL 2
31	2:03:58:30	LVLH	-30.0	0.0	0.0	1.60	

Tether Vent Computation

The ability to maintain an accurate state vector during TSS-1 operations depends upon accurately modeling the external forces acting on the orbiter. An analytical approach for determining the magnitude of the forces acting on the orbiter was formulated. The technique utilizes characteristics of the tethered system and in brief, can be viewed as the sum of the earth's gravitational force and the centrifugal force on the orbiter due to a rotating system and can be computed by ;

$$F = 3 X M w^2$$

where

F = tether force in the radial direction

X = distance between the orbiter's center of mass and the tether system center of mass

M = mass of the orbiter

w = angular velocity of the tether system center of mass

A set of mass properties were assumed for the orbiter and the satellite. The orbiter's mass and area were 6670.11 slugs and 2690 sq.ft., respectively. The satellite's mass was assumed as 37.69 slugs. The tether was assumed to have length of 20 km when fully deployed, its density was roughly 0.0001744 lb/ft. Given these initial conditions the tethered system's center of mass (c.m.) is roughly 424 feet radially above the orbiter's when the satellite is fully deployed. Using the analytical algorithm the magnitude of the force acting on the orbiter was computed as,

$$F_{TETHER} = 11.37 \text{ lbf}$$

Inherent in the MCC Trajectory applications exist the capability to solve for all of the external forces acting on the orbiter as reflected in the tracking measurements. The forces are computed in Shuttle body reference coordinates and utilizes the SB technique. Selecting an arc of tracking measurements during the onstation phase of the mission, the MCC solve-for force function computed the following forces,

$$F_x = 4.43 \text{ lbs} \qquad \& \qquad F_z = -9.90 \text{ lbs}$$

A limitation however, exist in the solve-for force tool. This important tool tries to solve for a constant force which is not the case during satellite deployment and retrieval. These phases of the TSS-1 profile are very dynamic with significant changes in the magnitude of the tether forces coupled with excessive pulses from the Reaction Control System (RCS) required to maintain prescribed attitudes. The RCS profile for the nominal mission profile is shown in Figure (1). It is not recommended that the solve for force technique be used during these dynamic periods, but instead utilize the analytical technique.

Navigation Results (Nominal Flight Profile)

The following section highlights the results of an analysis which determines the impacts to state vector accuracies when processing tracking measurements about the nominal TSS-1 mission profile. Of emphasis will be noted the impacts to navigation state vector accuracies when the tether forces were and were not modeled. Table (2) provides the tether force timeline used in the analysis.

Table 2
TETHER FORCE TIMELINE (Nominal Profile)

VENT	START TIME	END TIME	FX_LBS	FY_LBS	FZ_LBS
1	01:00:00:00	01:00:35:59	-0.50	0.00	0.00
2	01:00:36:00	01:01:45:59	0.10	0.00	-0.60
3	01:01:46:00	01:02:38:29	0.00	0.00	-1.60
4	01:02:38:30	01:03:44:59	2.00	0.00	-3.90
5	01:03:45:00	01:04:55:29	3.60	0.00	-7.40
6	01:04:55:30	01:16:29:59	4.30	0.00	-8.90
7	01:16:30:00	01:18:29:59	3.60	0.00	-7.40
8	01:18:30:00	01:20:14:59	2.80	0.00	-5.60
9	01:20:15:00	01:22:03:59	1.40	0.00	-2.50
10	01:22:04:00	02:02:02:59	0.70	0.00	-0.80
11	02:02:03:00	02:03:44:29	0.00	0.00	-1.00
12	02:03:44:30	02:05:30:00	0.00	0.00	-0.50

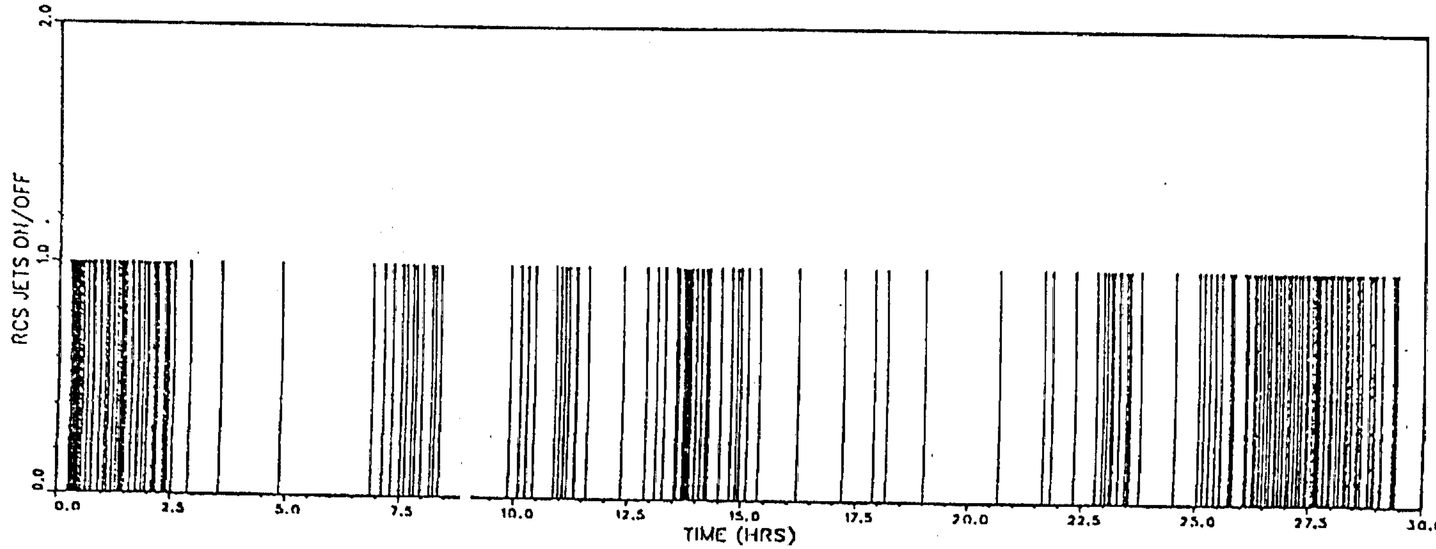

Fig. 1 RSC Profile (Nominal Mission)

Experience has shown that confidence in the knowledge of the orbiter's trajectory is determined by the stability observed in the changes in semimajor axis. Figures (2) and (3) provide plots of the magnitude of the change in semimajor axis denoted for each BB solution considered in the set of tracking measurement when the tether forces were not and were modeled, respectively. Taking note of the erratic signature displayed in Figure (2), the changes in semimajor axis appear very unstable with magnitudes that vary between 0 ft to 375 ft. Figure (3), on the other hand, shows that the magnitude of the changes in semimajor axis can be reduced by modeling the tether forces. Changes in semimajor axis observed in both plots during satellite deployment and retrieval are attributed to the occurrence of high amounts of RCS activity and the many attitude maneuvers seen over these periods.

To determine the error in each of the BB solution state vectors which were computed, a comparison was made with the reference ephemeris defined by STOCS. The set of ephemerides chosen for the compares were selected such that their timetags were within 30 seconds of the associating solution state vector.

A correlation between tether length, tension, attitude maneuvers, and the computed error in semimajor axis is noted in Figure (4). The magnitude of the error in general was roughly three to four times that of the center of gravity offset. This reinforces the fact that the BB solution state vectors were those computed to reflect a state about the c.g. of the system. Figure (5) shows the magnitudes of the error in semimajor axis resulting when the tether forces were modeled. As can be readily noticed, a significant reduction is made in the magnitudes of these errors.

Figure (6) through (11) show plots of the errors in the instantaneous position components resulting when the tether forces were and were not modeled. Of important note that should be mentioned when viewing these particular plots is that the c.g. offset manifests itself as an error in radial position when the forces are not modeled. The average error in radial position as shown in Figure (6) was roughly 471 ft, the c.g. offset at satellite full deployment is 424 ft. Further, when the forces are not modeled an extreme degradation in the knowledge of downtrack position is evident see (Figure (8)) and consequently, the ability to comfortably support contingency operations suffer. Figures (12) and (13) show the error seen in total position.

Ground State Vector Propagation Analysis

The MCC Ground Navigation section plays a very important role during the deorbit timeframe. Flight rules which govern the navigation accuracies required for a safe deorbit are strictly followed to assure crew safety. Current criteria dictates that the downtrack position error seen in the onboard navigation state will not exceed 20 nautical miles at the time of the deorbit burn. Acknowledging the fact that the TSS-1 mission is extremely complex, contingency plans and navigation accuracies which support them were analyzed.

The deorbit preparation timeframe starts approximately four revolutions prior to the deorbit burn. A preliminary state vector is provided to the FDO for computations necessary for the deorbit burn. A final state vector is delivered during the deorbit revolution. Given the nature and complexity of the TSS-1 mission, Ground Navigation flight controllers should be prepared at all times to support a contingency deorbit.

To satisfy the requirements levied by the flight rule which is mentioned above, validity tests were performed using the BB solution state vectors computed for each of the BB chains.

For the test, a selected set of solution state vectors from each BB chain were propagated for four revolutions and then compared to a corresponding state vector at the end of the propagation interval as defined by STOCS. Modeling of the tether forces were performed in the propagation interval for those vectors computed using the forces shown in Table (2).

Figure (14) provides plots of the magnitude of the error in semimajor axis resulting after the propagation of the solution state vectors computed for the two chains. The anchor time for the vectors used in this study are noted in Table (3). The plot readily shows the significant reduction in the magnitude of the error in semimajor axis when the tether forces are modeled. The magnitude of the error in semimajor axis remains about four times the c.g. offset for those vectors selected during satellite deploy and onstation operations when the forces are not modeled. The ground Navigation section strives to minimize the error in semimajor axis when tasked to provide state vectors to assist in trajectory planning.

Figure (15) shows the magnitude of the error in downtrack position resulting after each state vector propagations. As is expected, a correlation is seen between the error in semimajor axis and the downtrack position error for the two chains. Although the 20 nautical mile downtrack error criteria is not violated for either case, the case in which the tether forces were modeled provides the accuracies in both semimajor axis and downtrack position and thus may be confidently used for trajectory planning.

Table (3)
VECTOR PROPAGATION TIMES

PROP NO.	MET
1	00:33:00
2	02:01:00
3	03:37:00
4	05:14:20
5	06:51:00
6	08:27:40
7	10:03:40
8	11:39:00
9	13:15:00
10	15:15:28
11	18:05:00
12	19:41:40
13	22:07:40

Tether Cut Analysis

Given the complexity and technical unknowns associated with the TSS-1 mission, off-nominal mission scenarios needed to be analyzed. The scenario which will be discussed in this section addresses the ability of the Navigation section to successfully provide accurate solution state vectors in the event the tethered is cut voluntarily or involuntarily. The physical properties of the tethered system concludes that when the tether is cut, a decrease in orbital energy results in the Shuttle's trajectory. The following analysis addresses the

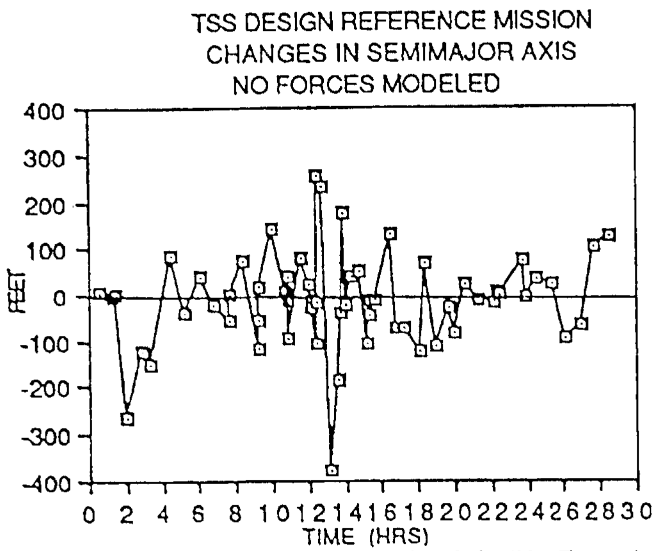

Fig. 2 Changes in Semimajor Axis (No Forces)

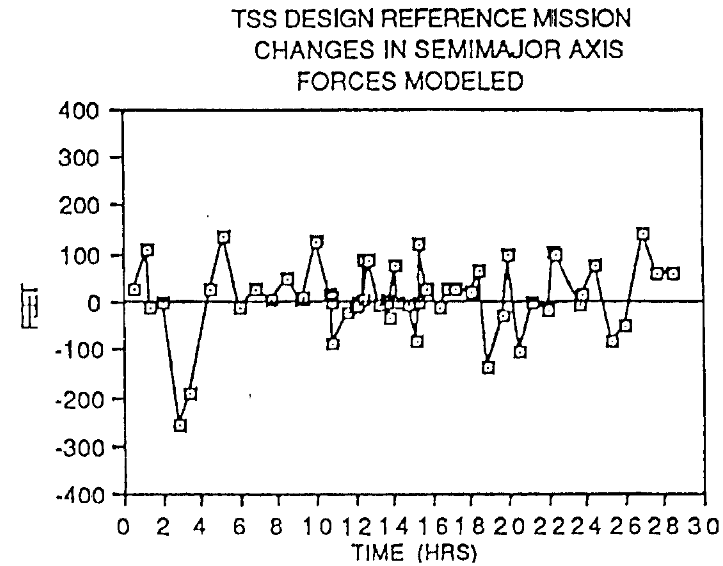

Fig. 3 Changes in Semimajor Axis (Forces)

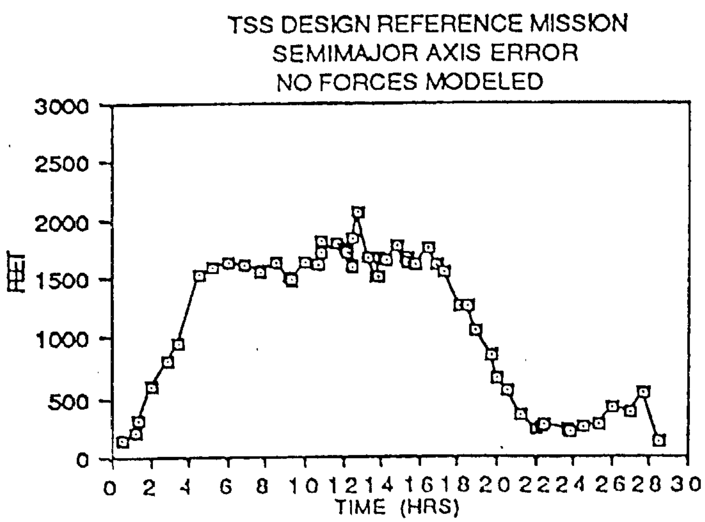

Fig. 4 Error in Semimajor Axis (No Forces)

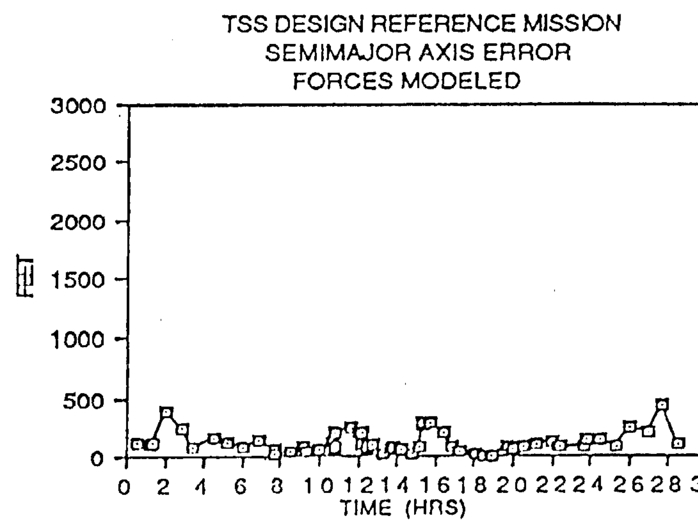

Fig. 5 Error in Semimajor Axis (Forces)

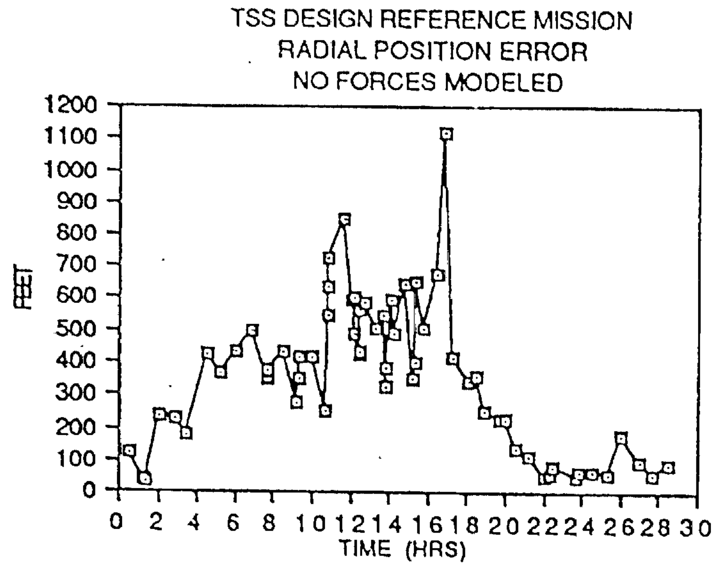

Fig. 6 Radial Position Error (No Forces)

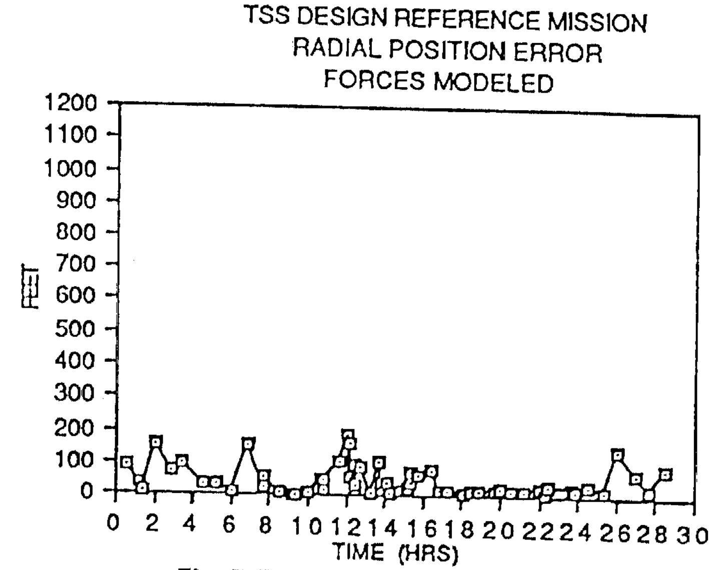

Fig. 7 Radial Position Error (Forces)

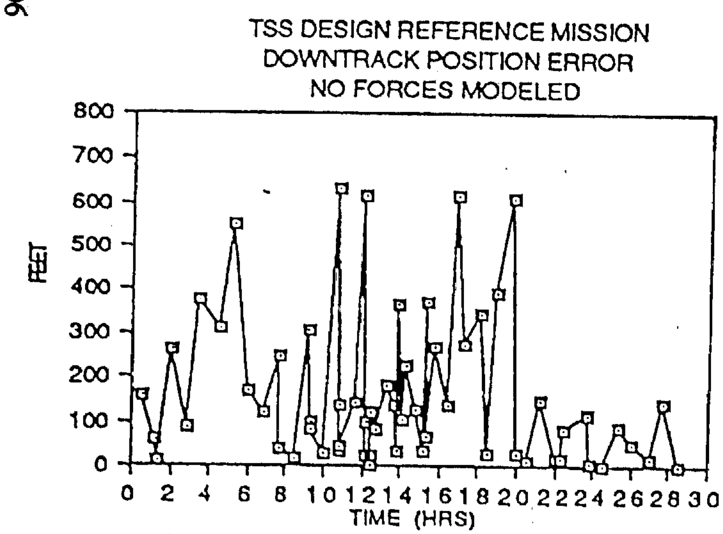

Fig. 8 Downtrack Position Error (No Forces)

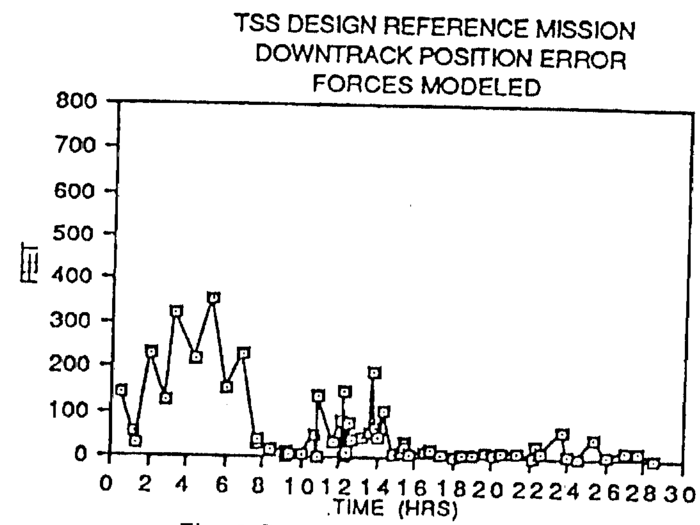

Fig. 9 Downtrack Position Error (Forces)

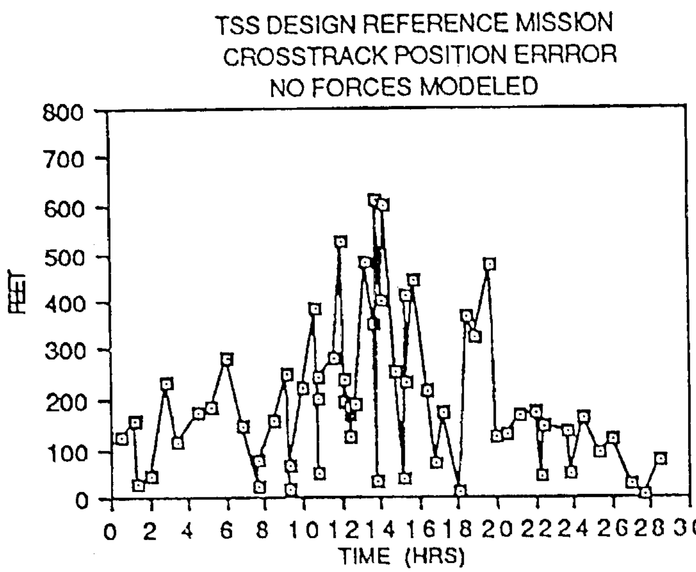

Fig. 10 Crosstrack Position Error (No Forces)

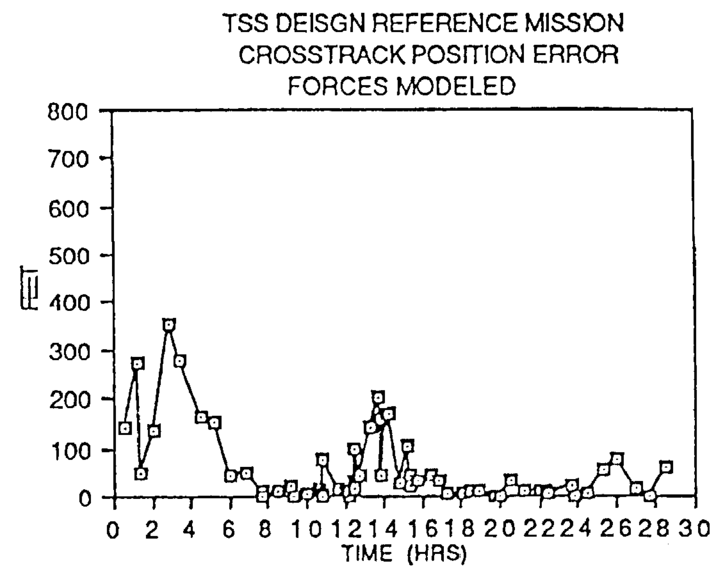

Fig. 11 Crosstrack Position Error (Forces)

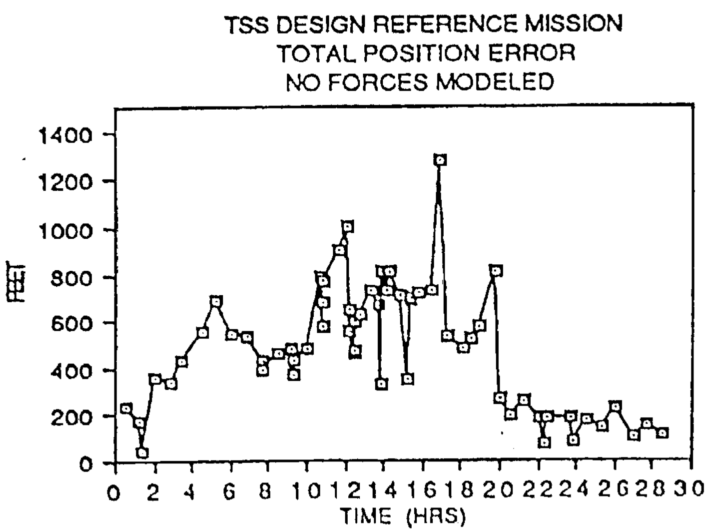

Fig. 12 Total Position Error (No Forces)

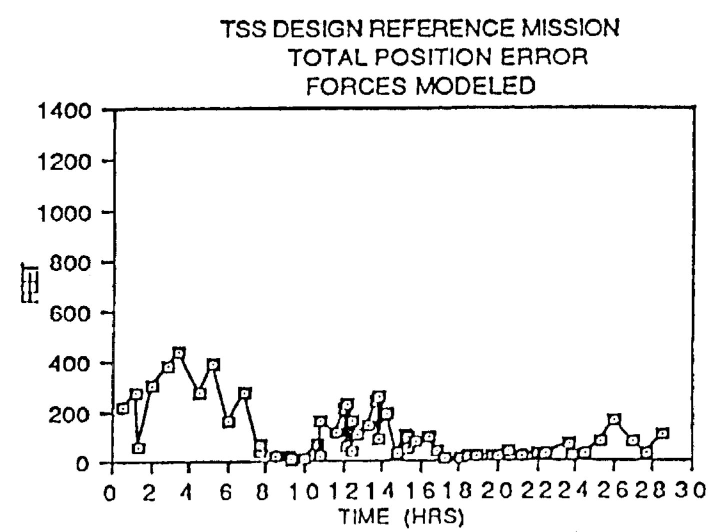

Fig 13. Total Position Error (Forces)

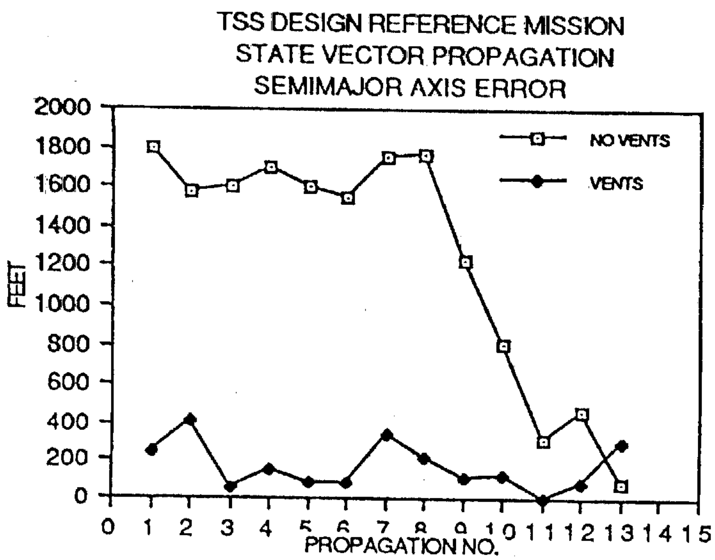

Fig 14. Semimajor Axis Error

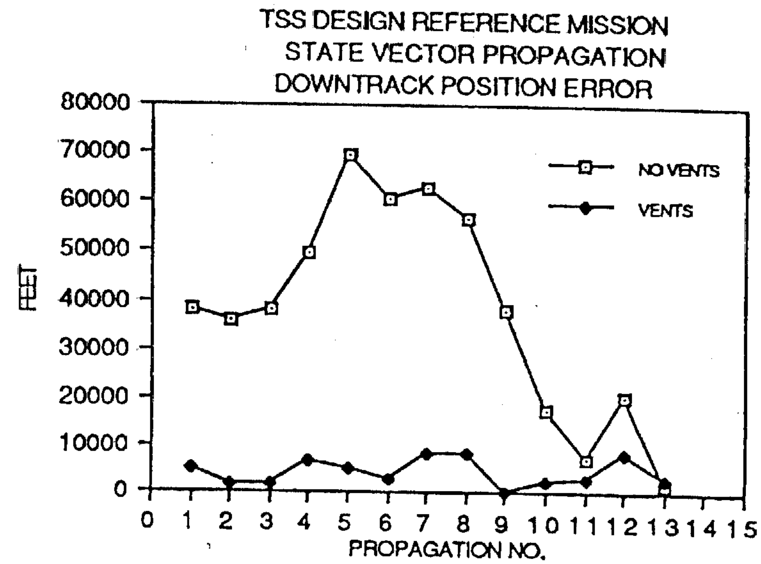

Fig 15. Downtrack Position Error

amount of time required to determine the new trajectory as reflected in the tracking measurements. The analysis includes discussions of the results of a tether cut at 5, 10, 15, and 20 km. The occurrence of the tether cuts are depicted in Figure (16).

The analysis was performed with the aid of tracking measurements computed using both STDS and the Houston Operations Predictor Estimator (HOPE) programs. STDS was used for the creation of the tracking measurements which included tether induced perturbations prior to the tether cut. HOPE was used to create the tracking measurements after the tether cut and utilized a state vector as defined by STOCS which coincided with the time of the tether cut. The tracking measurements were merged to create one master tracking data file and were processed in the BB mode with and without the tether forces being modeled.

In each of the cases analyzed, the stop time of the modeled tether force coincided with the time of the tether cut. The assumption used in this scenario was that the tether forces' stop time modeled in the Ground Navigation software could be readily modified to reflect the actual time of the cut during real-time operations. This assumption was also adopted when assessing the Onboard Navigation system performance. However, the onboard tether force will not likely be zeroed at the exact time of the tether cut due a combination of ground flight controller and crew interventions necessary in accomplishing this task. Each case was therefore analyzed to determine what were the net effects if the tether forces were never zeroed out and represents a three sigma procedural scenario.

Basic orbit mechanics dictates that the position at which the tether cut occurs will become the new apogee for the Shuttle's orbit. The perigee will be defined 180 degrees away from the tether cut, see Figure (17). The tether cut introduces an instantaneous removal of the tether tension. This analysis will show that when the tether forces are not modeled in the navigation software, the instantaneous removal of tether tension appears as a semimajor axis change in the solution state equal to roughly four times the c.g. offset distance. The analysis will also show that when the tether forces are modeled in the timeframe prior to the tether cut and properly zeroed out that a smooth transition to the new orbit can be achieved.

Trajectory Analysis (Tether Cut)

The results of BB processing for the error in semimajor axis are shown in Figure (18) through (21). The error is computed when a comparison is made between each BB solution and a chosen ephemeris vector. For the case in which tether forces were modeled, the forces were modeled only at the times prior to the tether cut. The plots readily show that a smooth transition to the new orbit is achieved upon accurately modeling the tether forces prior to the cut. For the cases in which the forces were not modeled the resulting error in semimajor axis is directly proportional to the length at which the tether is cut. As is shown when the tether length is 20 km, a large error results for the case in which the forces were modeled. The error can be attributed not only to the inaccuracies in the BB solution state vectors computed, but also the impact of high RCS activity as is shown in Figure (1).

In determining whether the Flight Rule which governs the navigation state vector accuracies in the event of a Loss of Communication between the ground and the Shuttle, a two revolution navigation accuracy analysis was performed. Each case was analyzed to determine when the 20,000 ft predicted downtrack position error criteria was violated.

For the chains in which the tether forces were not modeled the criteria was violated in a very short time. In the case at which the cut occurred at 20 km, the violation occurred within one orbital revolution. Whereas for the 5 km case, the violation was delayed for just over two revolutions. When however, the tether forces were modeled the magnitude of the downtrack error prediction in two revolution resulting after the cut was minimized. In these cases, no update would be required to the reference ground ephemeris following the tether cut given the smooth transition to the new orbit as displayed in Figure (22) through (25).

Each of the BB chains for the tether length analyzed were compared against truth vectors as defined by STOCS and HOPE during pre-and post tether cut phases, respectively. Figures (26) through (29) show the error in semimajor axis resulting after each vector compare. The statistics show the magnitude of the the error in each solution when compared to the orbiter's true position and also the time required to recover a ground solution of the quality necessary to support trajectory planning. For the cases in which the tether forces were not modeled prior to the cut, the solution converged within a rev after the cut. For the four cases which acknowledged the tether forces, the solution remains very close to the truth and no recovery time is necessary. The error in total position for the the chains are shown in Figures (30) through (33).

Conclusions

The TSS-1 mission will indeed be a challenging undertaking for the STS program. The dynamics which are expected during tethered operations will require that new real-time navigation flight procedures be developed to meet all mission objectives and to assure crew safety. The results have shown that with proper modeling of the tether forces acting on the orbiter, accurate prediction of the true state of the orbiter can be maintained under both nominal and off-nominal flight conditions. This will not be a trivial task and will require that pertinent systems information be made readily available to the navigation team during TSS-1 operations. Precise coordination between ground flight controllers and the crew must be maintained to properly monitor the true state of the orbiter. This can only be accomplished through extensive training in an integrated MCC simulation environment.

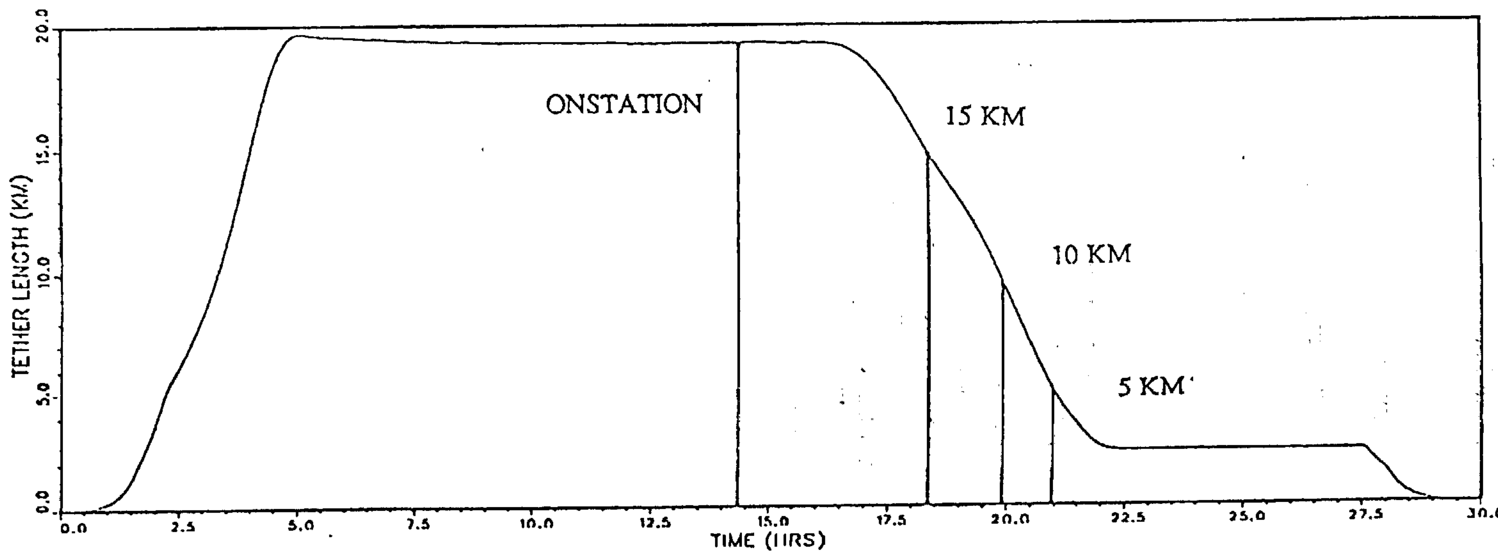

Fig 16. Tether Length VS. Time

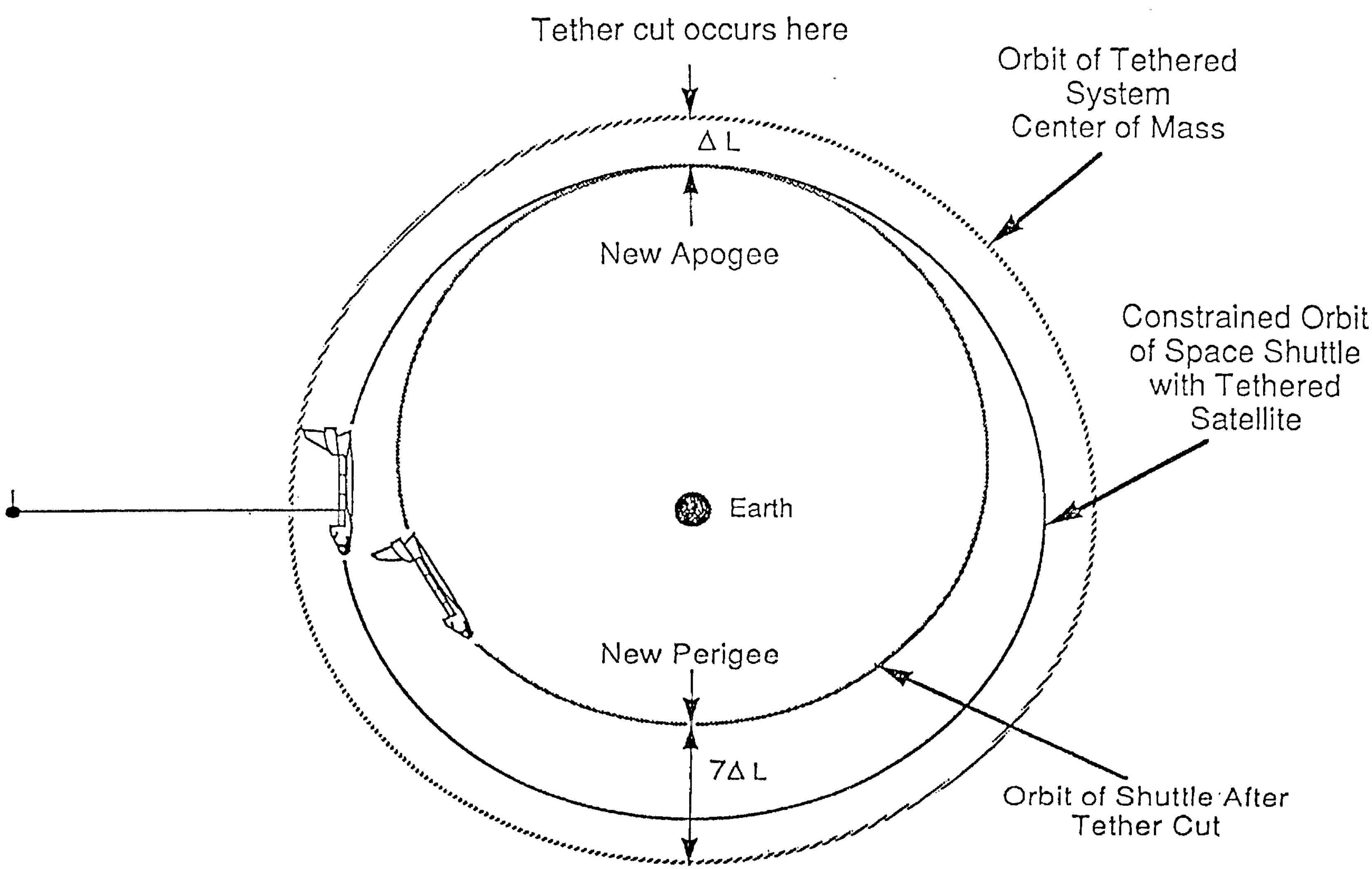

Fig 17. Orbits Defined After Tether Cut

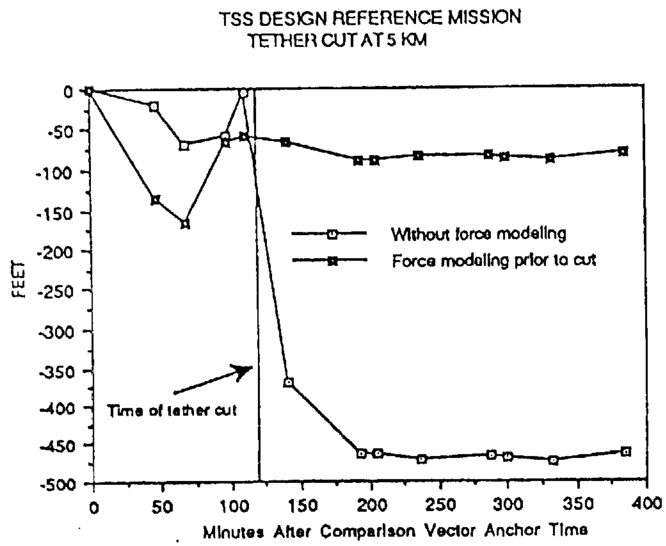

Fig 18. Semimajor Axis Error (Length - 5 km)

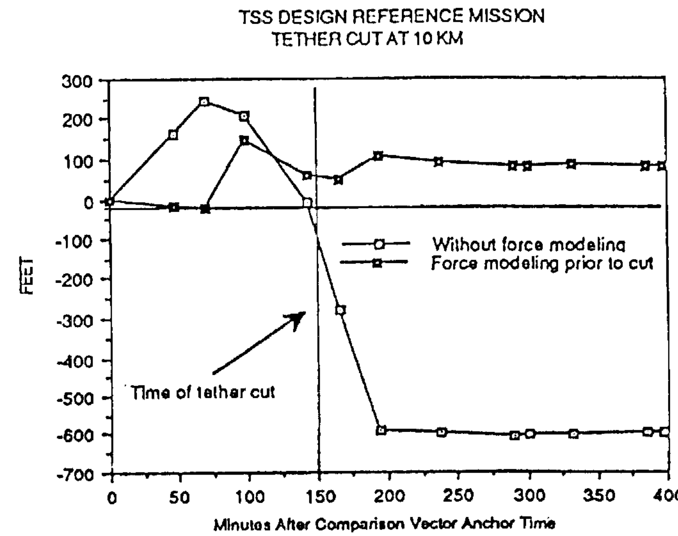

Fig 19. Semimajor Axis Error (Length - 10 km)

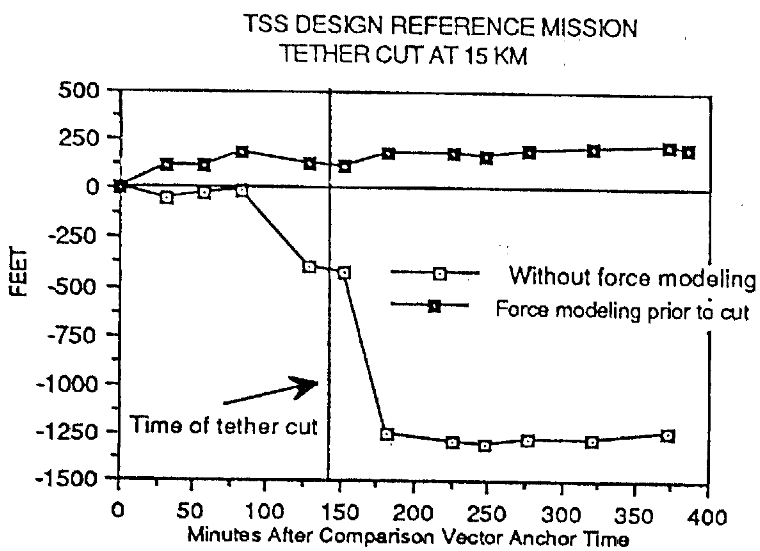

Fig 20. Semimajor Axis Error (Length - 15 km)

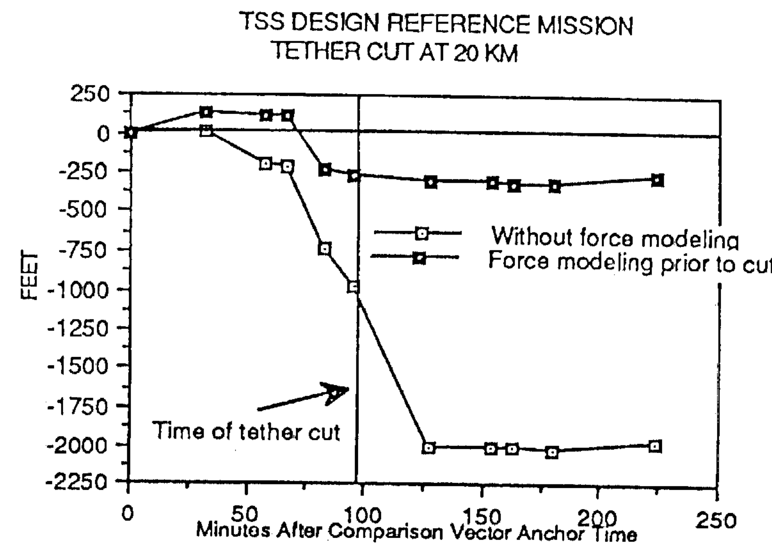

Fig 21. Semimajor Axis Error (Length - 20 km)

TSS DESIGN REFERENCE MISSION
TETHER CUT AT 5 km

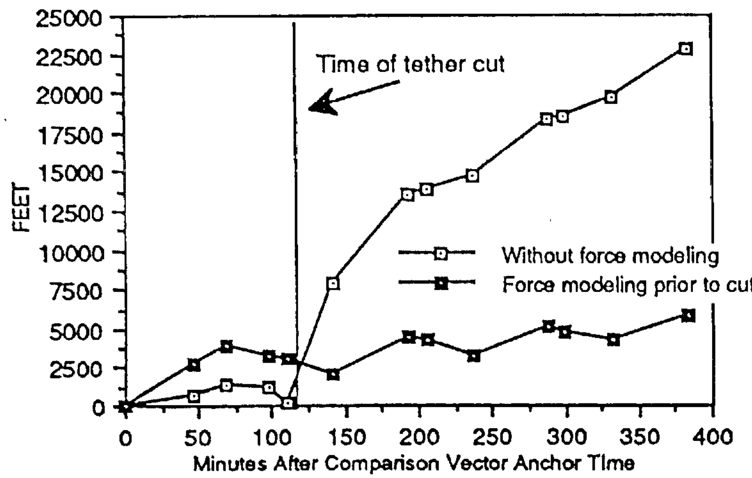

Fig. 22 Downtrack Error 2 Rev's (Length - 5 km)

TSS DESIGN REFERENCE MISSION
TETHER CUT AT 10 Km

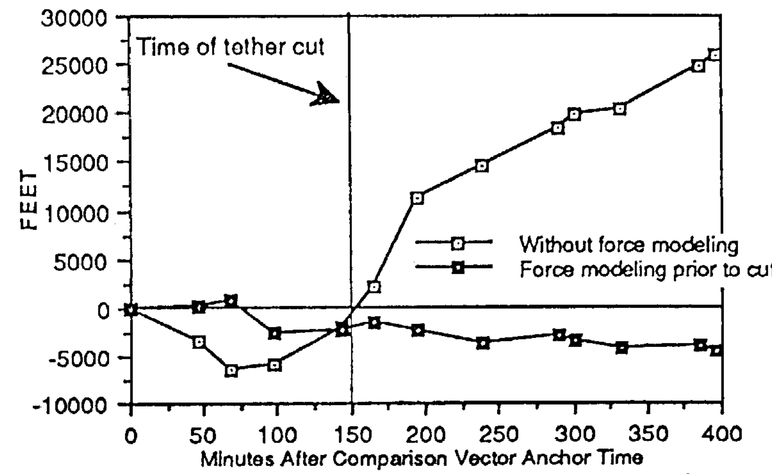

Fig 23. Downtrack Error 2 Rev's (Length - 10 km)

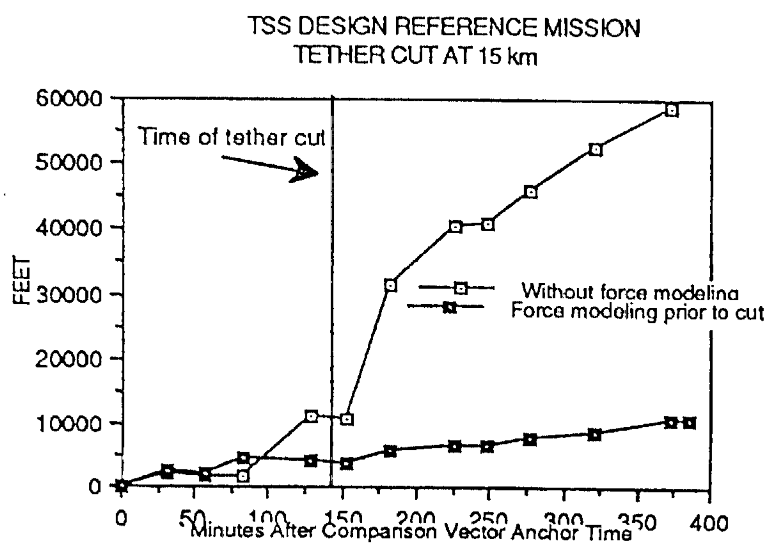

Fig. 24 Downtrack Error 2 Rev's (Length - 15 km)

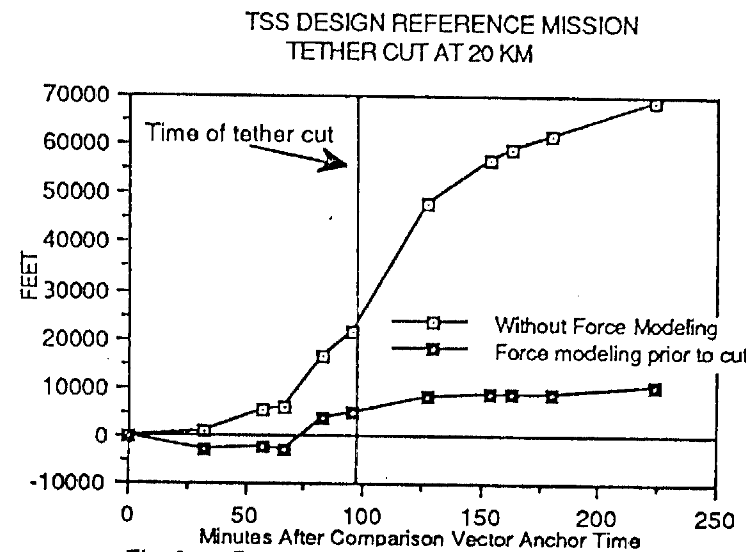

Fig 25. Downtrack Error 2 Rev's (Length - 20 km)

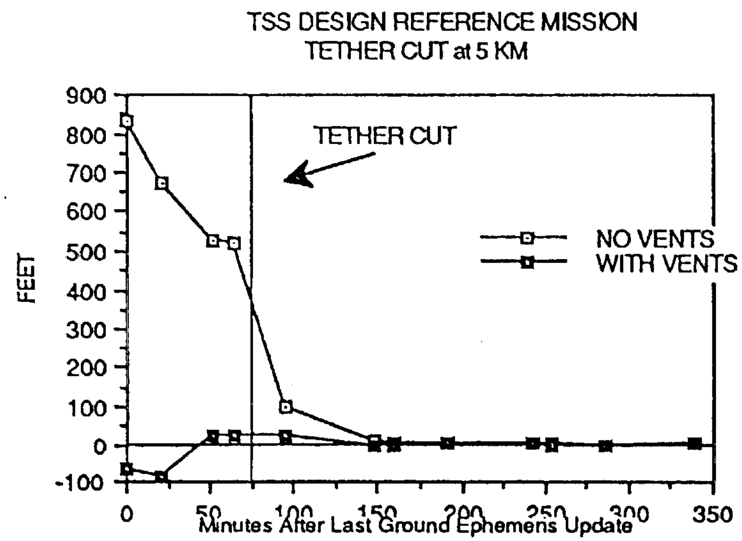

Fig 26. Semimajor Axis Error (Length - 5 KM)

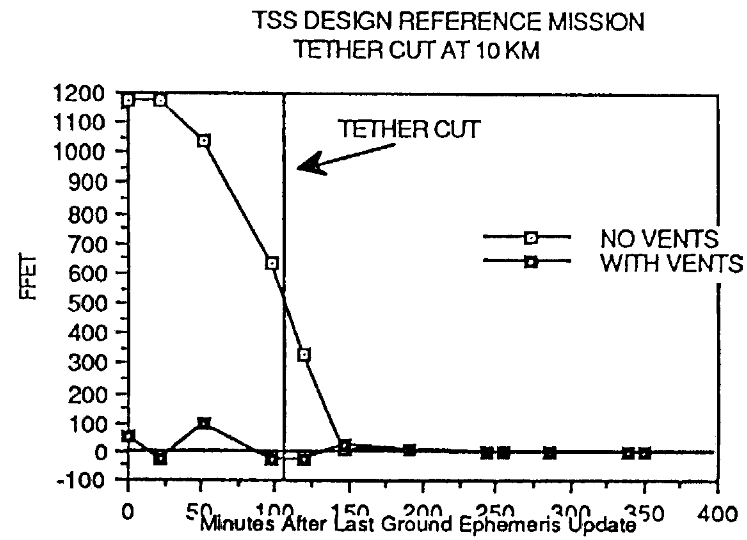

Fig. 27 Semimajor Axis Error (Length - 10 km)

TSS DESIGN REFERENCE MISSION
TETHER CUT AT 15 KM

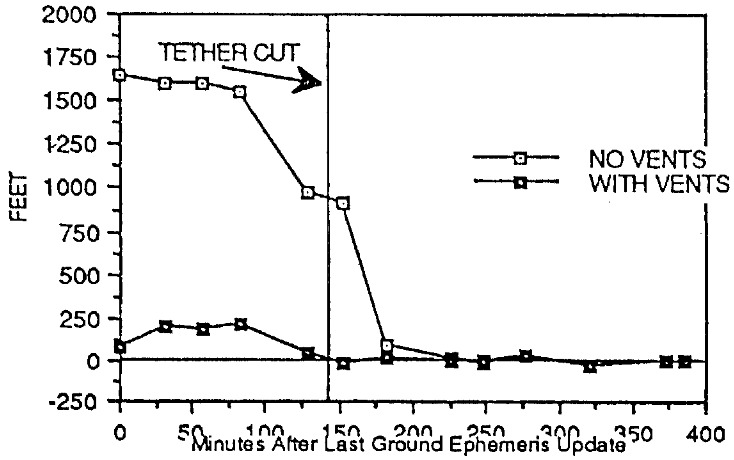

Fig. 28 Semimajor Axis Error (Length - 15 km)

TSS DESIGN REFERENCE MISSION
TETHER CUT AT 20 KM

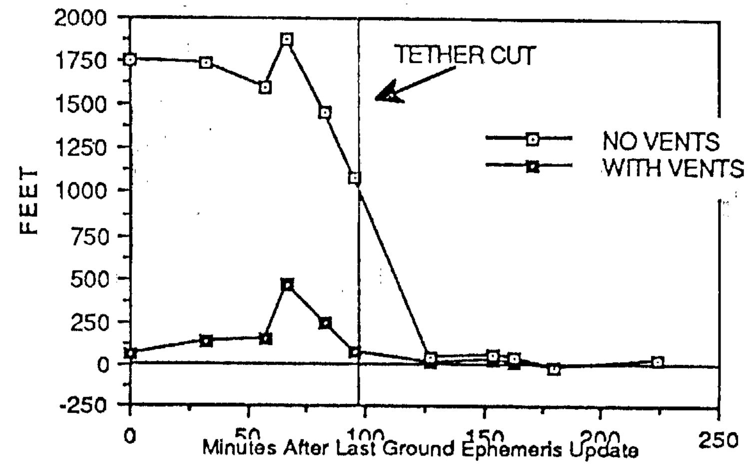

Fig 29. Semimajor Axis Error (Length -. 20 km)

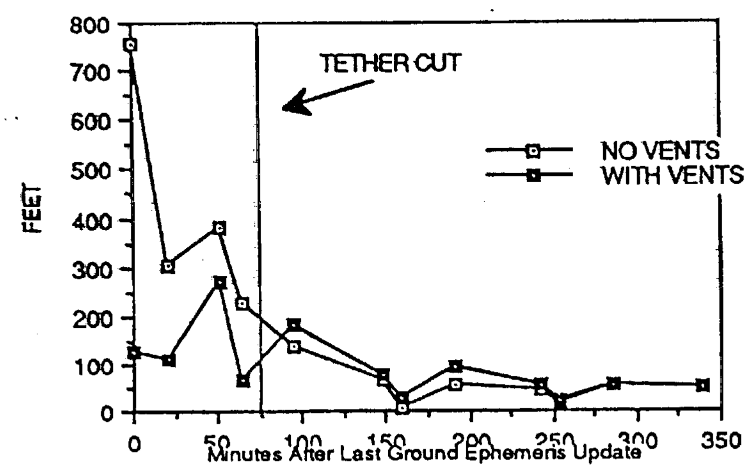

Fig. 30 Total Position Error (Length - 5 km)

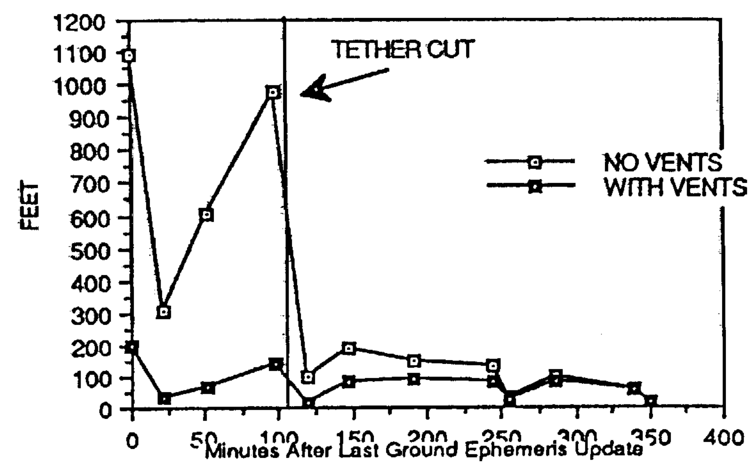

Fig. 31 Total Position Error (Length - 10 km)

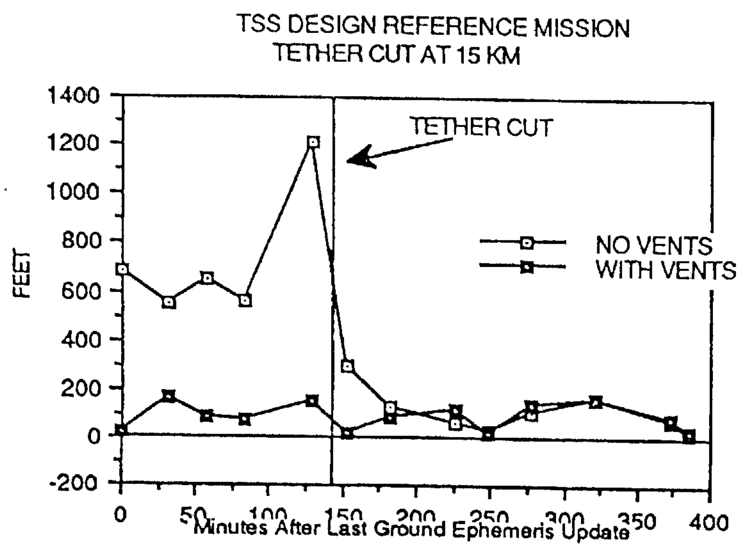

Fig. 32 Total Position Error (Length - 15 km)

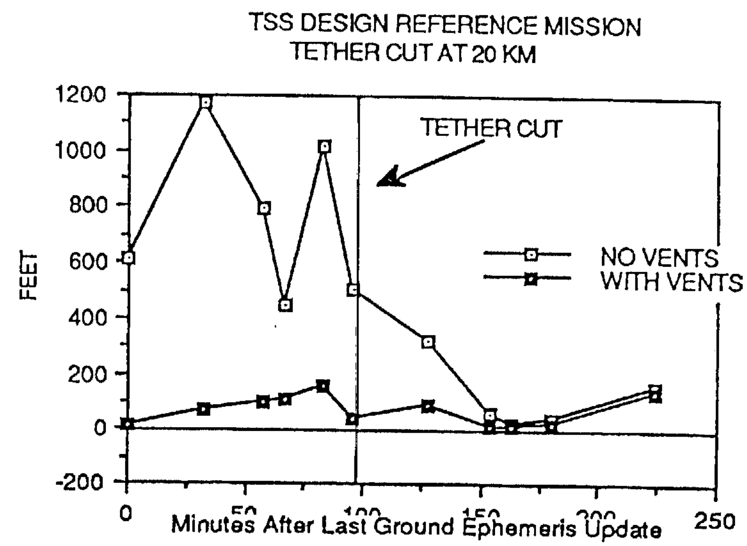

Fig. 33 Total Position Error (Length - 20 km)

References

1. Zimmerman, P.L., "Impacts of Tether Cutting on Ground Navigation", August 22, 1990, STSOC Transmittal Form #FDD-NAV-640-90-041.

2. National Aeronautics and Space Administration, "STS Operational Flight Rules", January 20, 1989, Document No. JSC-12820.

3. Zimmerman, P., "Generation of Tether Cut Tracking Data Files for use with SONAV", May 10, 1990, STSOC Transmittal Form #FDD-NAV-640-90-024.

4. Hass, L., "Ground Navigation Vent Modeling of the Tethered Satellite System", April 25, 1990, STSOC Transmittal Form #FDD-NAV-620-90-018.

5. Jackson, T.C., "Ground Navigation Analysis of TSS-1", July 19,1990, STSOC Transmittal Form #FDD-NAV-640-90-053.

FLIGHT MECHANICS/ESTIMATION THEORY SYMPOSIUM

MAY 21-23, 1991

SESSION 2